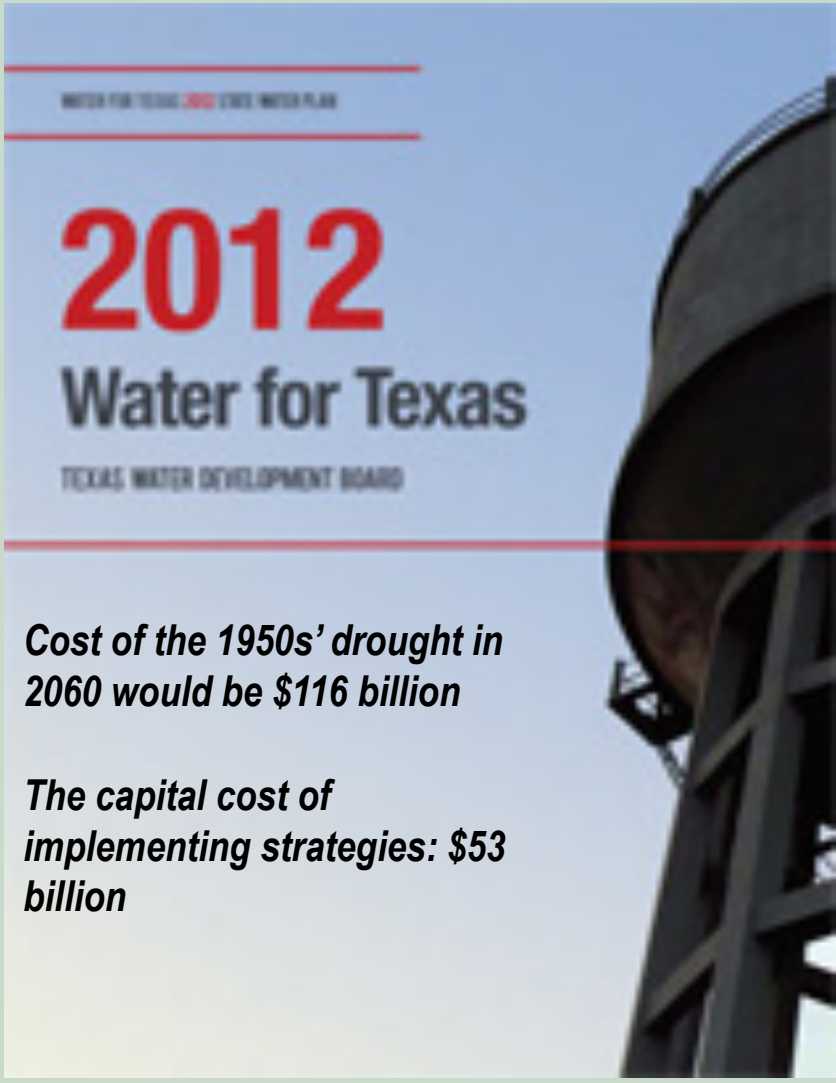
Assessing Future Changes of Drought and Extreme Surface Temperatures over the South-Central United States

Rong Fu
Nelun Fernando, Lei Yin, Tong Ren, Ze Yang, Adam Bowerman
Jackson School of Geosciences, The University of Texas at Austin

NOAA MAPP 2012-2013 Webnar Series
January 15th, 2013



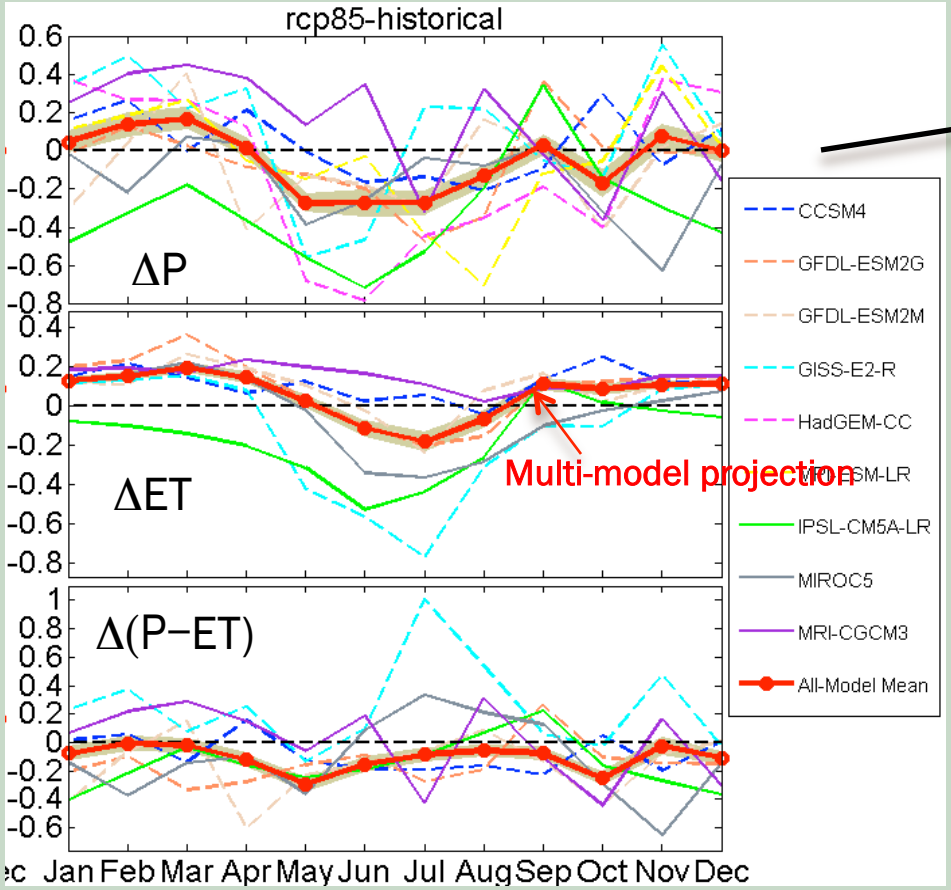
Cost of the 1950s' drought in 2060 would be $116 billion

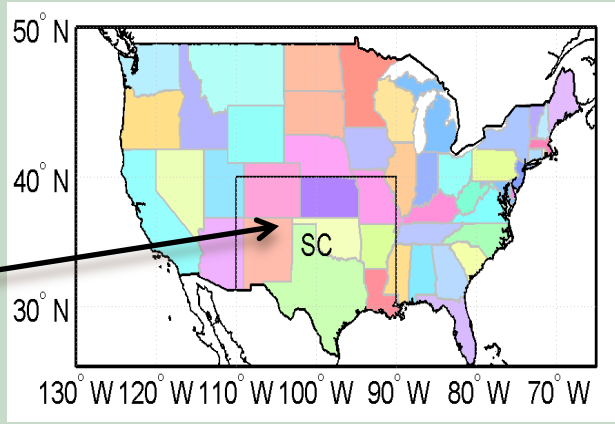
The capital cost of implementing strategies: $53 billion

Based on Fu et al. 2012, revising for J. Climate

The projected change of P-ET by the CMIP5 Models

Projected change during 2073-2099 relative to 1979-2005 for RCP8.5





The nine models used in the projections:

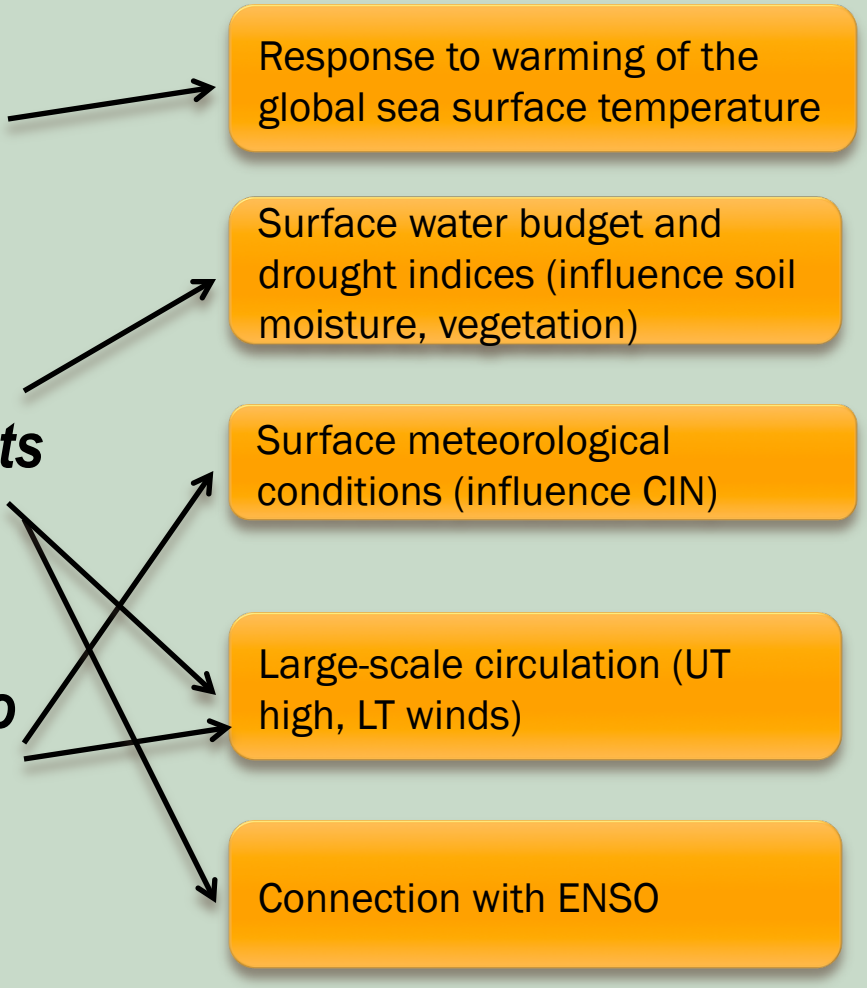
CCSM4(5), GFDL-ESM2G (1), GFDL-ESM2M(1), GISS-E2-R (5), HadGEM2-CC(1), MPI-ESM-LR (3), IPSL-CM5A-LR(4), MIROC5(3), MRI-CGCM3(1)

How can we reduce the uncertainty of the climate projection?

- ***Does the multi-models ensemble projection necessarily out-perform individual model projection over SC US?***
  - ***Gleckler et al. (2008), Pierce et al. (2009): An ensemble mean, especially a multi-model ensemble mean projection, can out-perform the best quality model because the former allows cancellation of offsetting errors in the individual global models.***
  - ***What should we do if majority of the models have similar biases?***

Criteria for our process-based model evaluation Metrics:

- ***Relevant to climate projection***
- ***Capture processes that control droughts over Texas***
- ***Can be compared to long-term observations***



Datasets and Models:

Datasets:

- *CPC US-Mexico daily rainfall (Higgins et al. 1996), 1°,*
- *GHCN daily Tmax,Tmin (Vose et al. 1992), 2.5°*
- *NLDAS (Rodell et al. 2004), ET, 1/8°, 1980-2007.*
- *ERSSTv3b SST (Smith et al. 2008), 2.0°, 1854-2005*
- *NCEP reanalysis (Kalney et al 1996; Kistler et al. 2001), 2.5°, 1948-present*

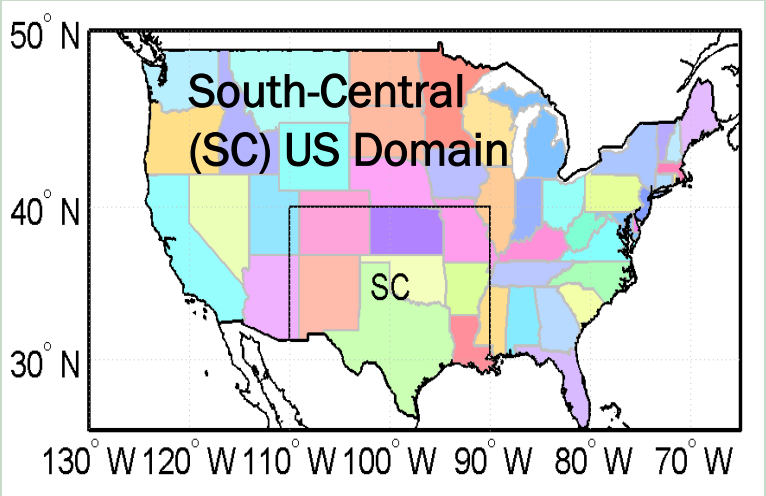
CMIP5 models:

CCSM4(5), GFDL-ESM2G (1), GFDL-ESM2M(1), GISS-E2-R (5), HadGEM2-CC(1), MPI-ESM-LR (3), IPSL-CM5A-LR(4), MIROC5(3), MRI-CGCM3(1)

All the datasets and models are re-mapped to 2.5° spatial resolution

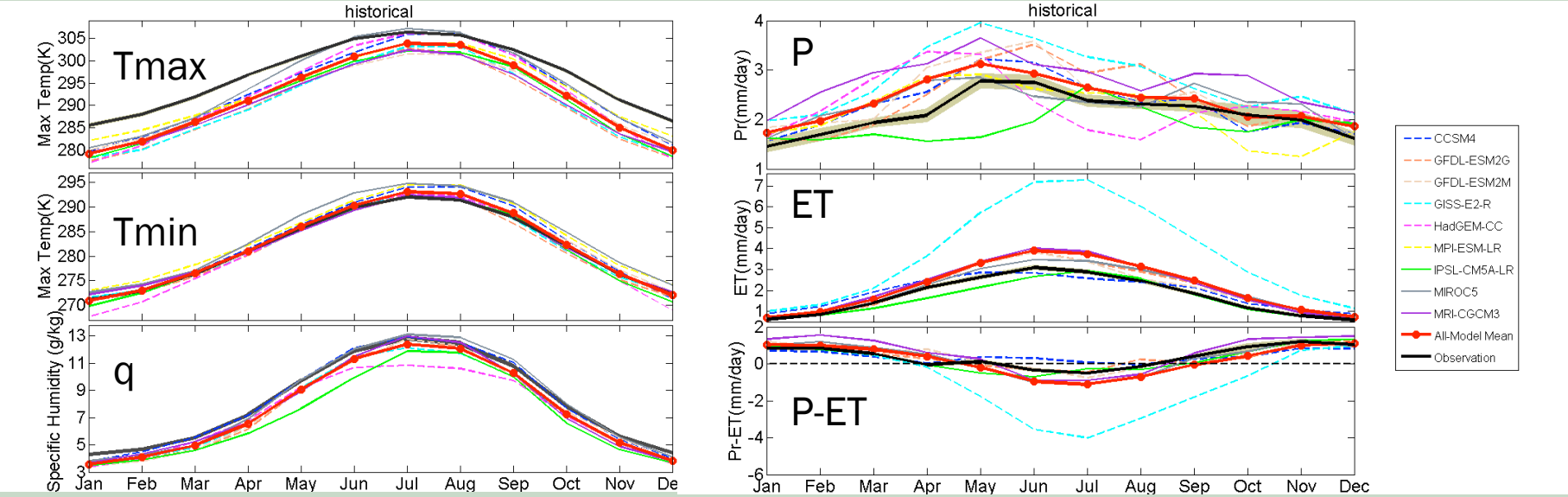
Periods:

- *1950-2005; meteorological data*
- *1900-2005: global SST warming related change*
- *1980-2005: surface energy/water balance.*



Evaluate seasonal cycles of climatic surface conditions:

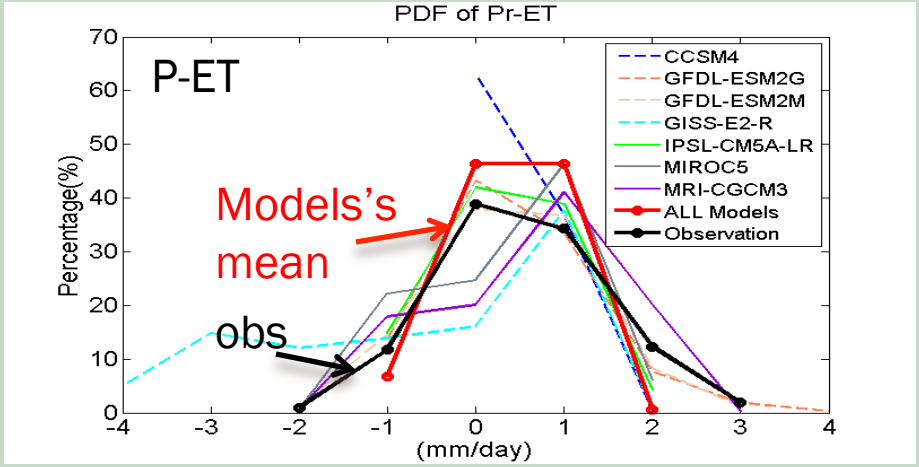
- ***Cold bias in daily maximum surface temperature (Tmax)***
- ***Overestimate Precipitation (P), Evapotranspiration (ET), esp. during spring & summer, overestimate net surface water loss in summer and fall.***
- ***Large discrepancies in seasonal rainfall***



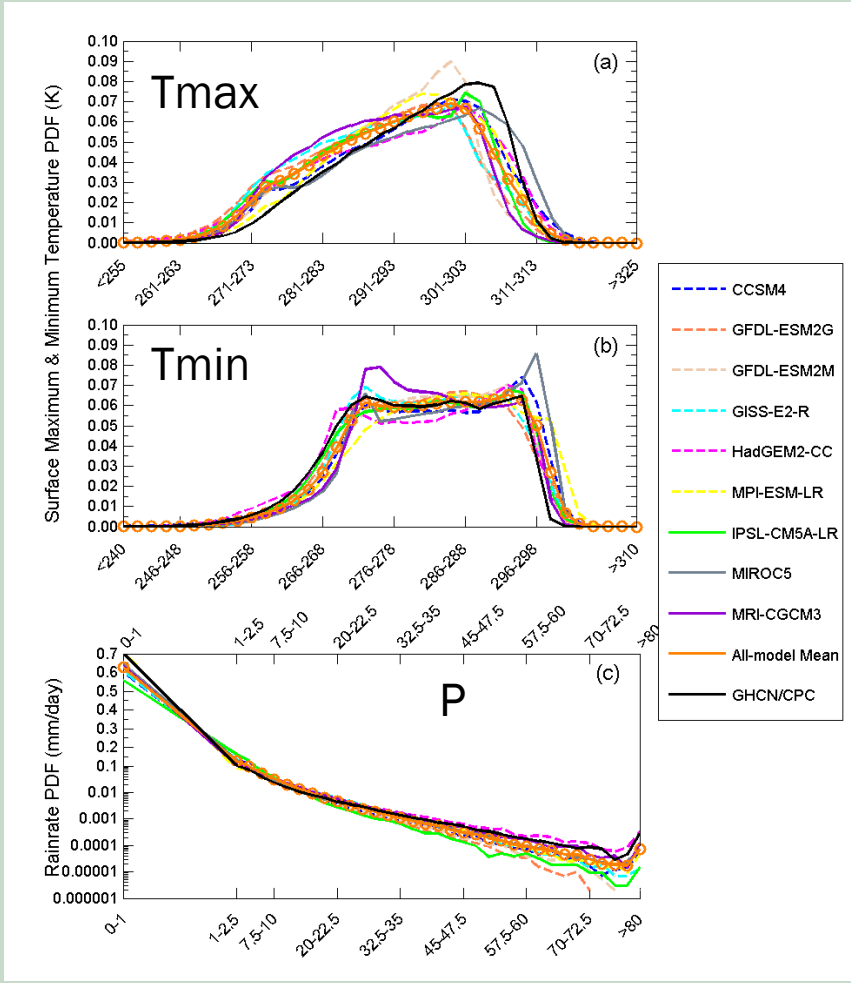
Black line: observations, Bold Red line: multi-model ensemble mean

Probability distributions of Tmax, Tmin, P-ET:

- ***Tmax: underestimate warmer Tmax and overestimate cooler Tmax***
- ***Tmin: underestimate cooler Tmin, overestimate warmer Tmin (consistent with wet bias)***
- ***P: underestimate non-rain and heavy rainrate, overestimate light rainrate.***
- ***Multi-model ensemble underestimates variability of the P-ET, esp. extreme anomalous P-ET.***

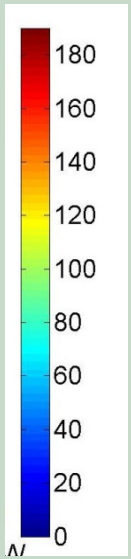


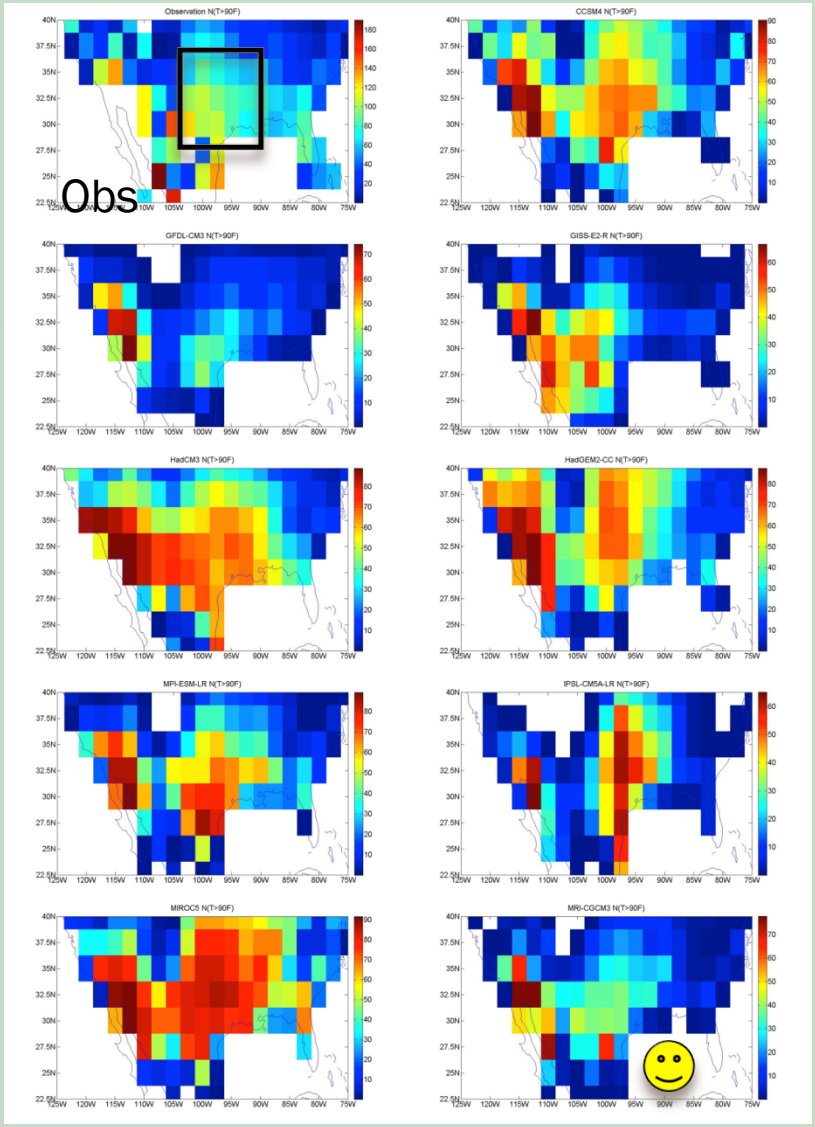
Black line: observation, Orange line: multi-model ensemble



Number of days/yr when T_{max}>90F:

- ***Reverse the E-W gradient of extreme Tmax over Texas,***
- ***Most of models overestimate occurrence of extreme Tmax over the southeastern Great Plains,***
- ***Large inter-model discrepancies***

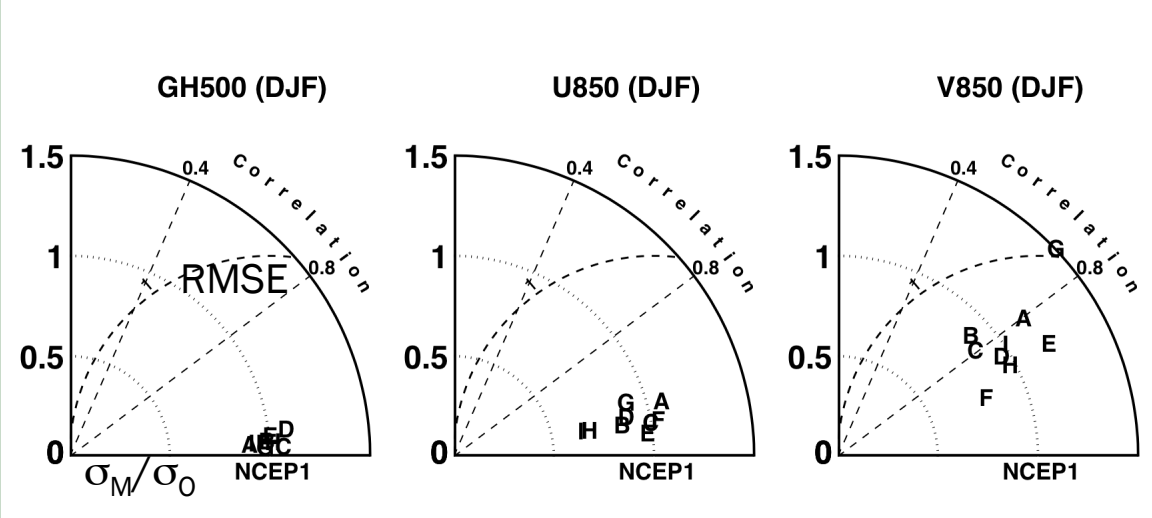


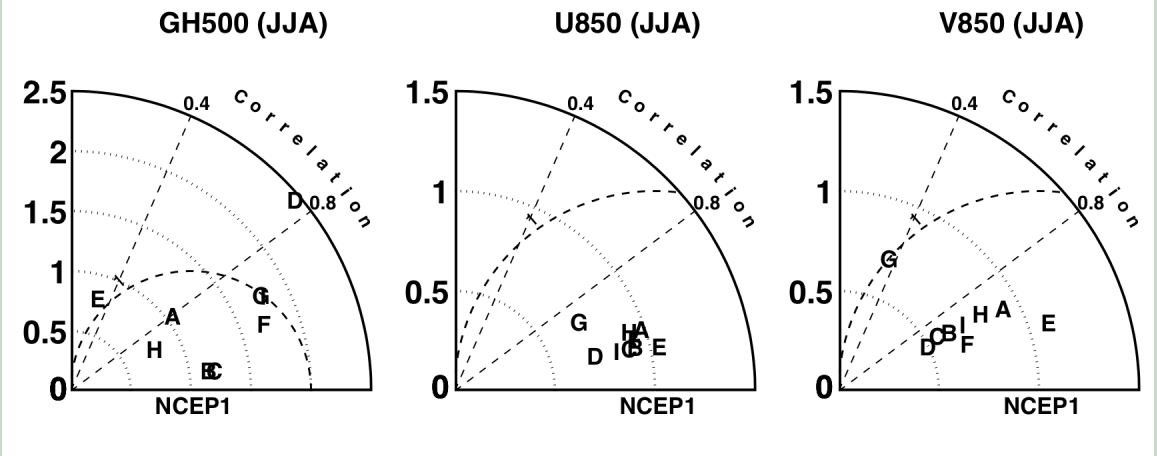


Evaluation of Large-scale atmospheric circulation:

- *JJA 500hPa Z: HadGEM2, MPI, IPSL, GISS-E2R, MRI have large spatial MSRE. Mid-tropospheric ridge is too weak or too strong.*

- *Variability of U850, V850 are generally too weak.*

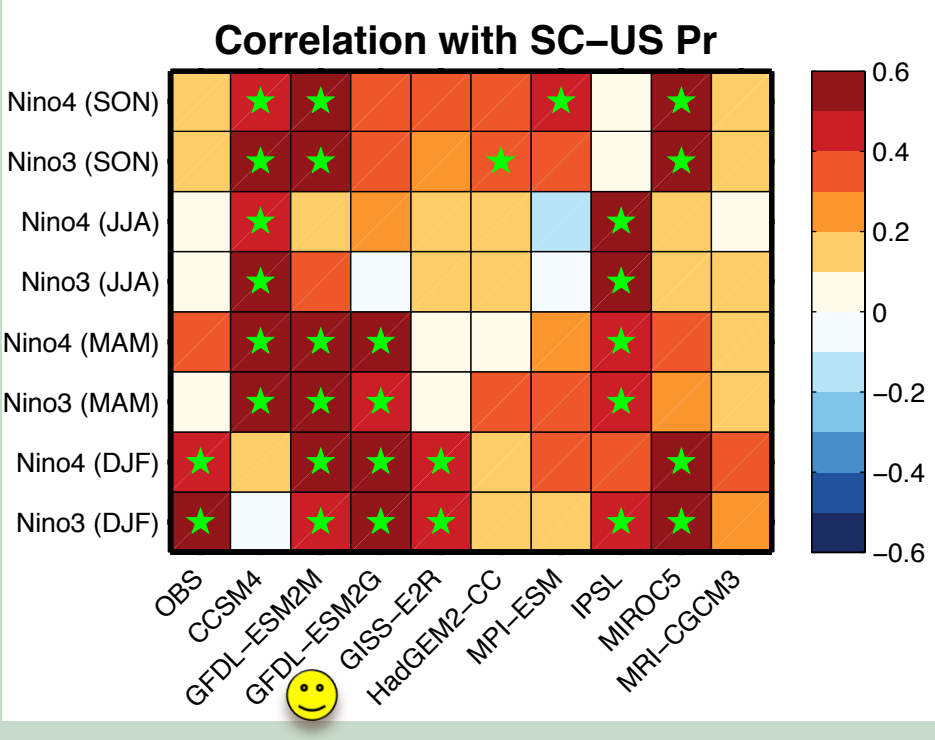




Correlation between SC US rainfall anomalies and Niño3 and Niño4 indices:

About 50% of the models

- ***underestimate correlation with ENSO in winter***
- ***overestimate ENSO connection in spring, summer and fall***
- ***Because of errors in ENSO tele-connection pattern.***

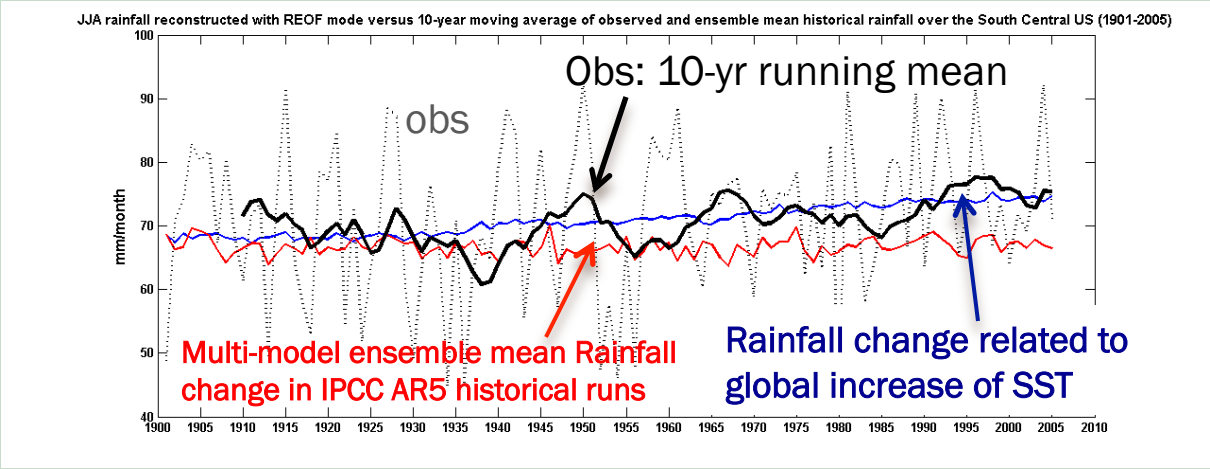


"Star" indicates significant correlation coefficient at 95% confidence level using student t-test.

Modeled response of summer rainfall over SC US to the global SST warming mode:

- ***Most of the models cannot reproduce the observed change of summer rainfall over SC US associated with global increase of SST over the period of 1900-2005.***

- ***Except for CCSM4, these CMIP5 models cannot captures the observed relationship between the increase of global SSTs and increase of annual rainfall over SC US.***



Observed/Model	r-value
Observed	***0.25***
CCSM4	0.16
GFDL-ESM2M	-0.16
GFDL-ESM2G	***-0.45***
GISS-E2R	-0.03
HadGEM2-CC	-0.12
MPI	0.05
IPSL	***-0.28***
MIROC	-0.17
MRI-CGCM3	0.06

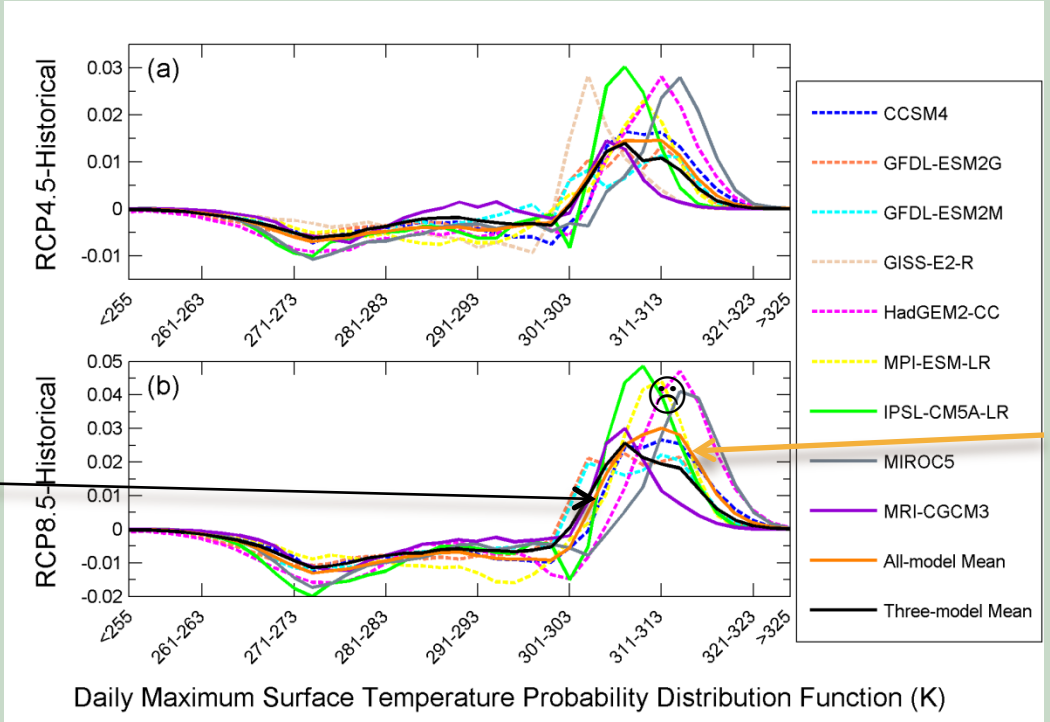
Bold-italics: statistically significant
Red: correct sign
Blue: incorrect sign

How does models' quality influence climate projection?

Tmax during 2073-2099 relative to 1979-2005:

- ***Models consistently project a disproportional increase of occurrence of high Tmax (>86F - 117F) by***
  - ***25-50% under RCP4.5 scenario (CO_2 reaches 650 ppm by 2100), 50-100% under RCP8.5 scenario (CO_2 reaches 1350ppm by 2100)***
- ***Ensemble projection without less reliable models project a weaker increase of extreme high Tmax, relative to all-model ensemble projection.***

Ensemble mean of better performing models

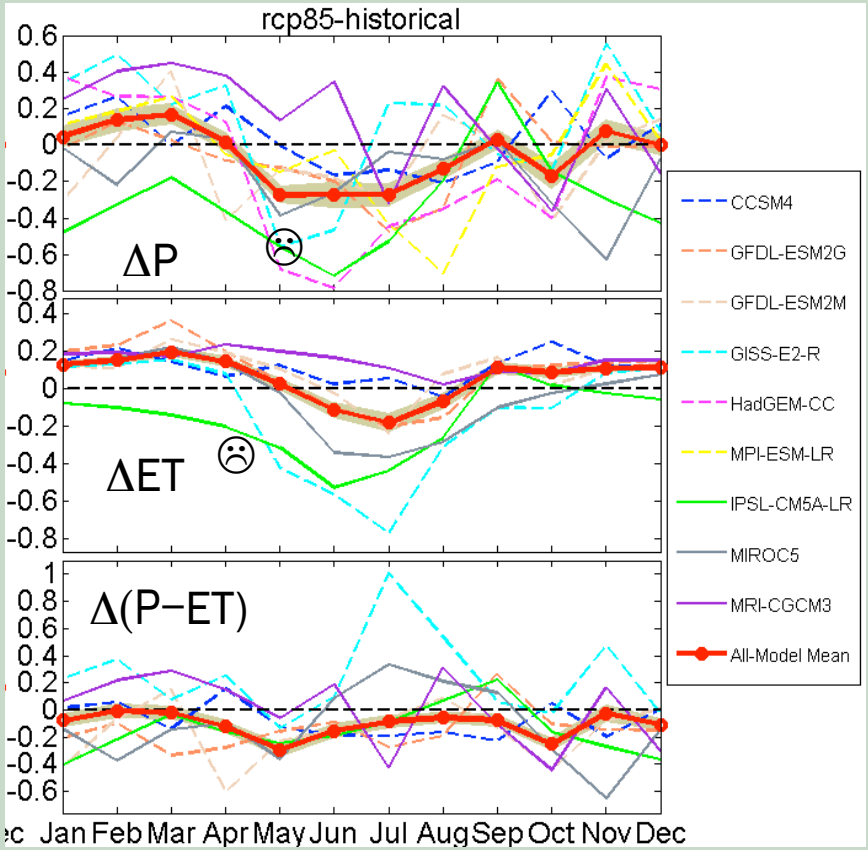


All- model ensemble mean

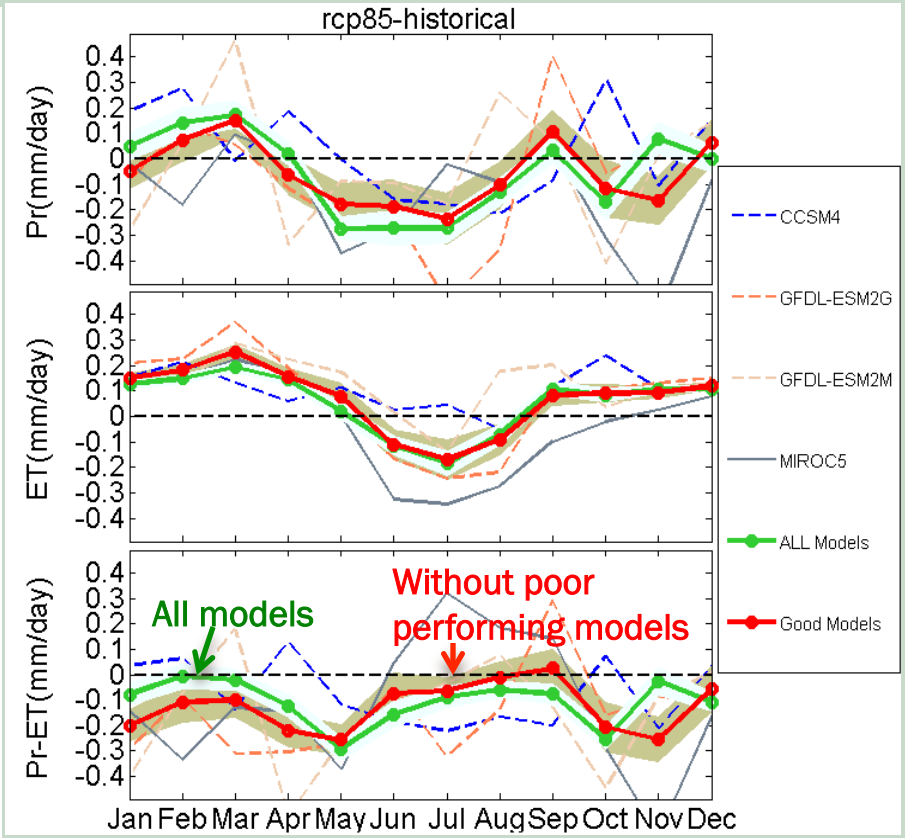
Projected P-ET change (RCP8.5) during 2073-2099 relative to 1979-2005:

- ***Multi-Model ensemble project increase rainfall and ET in winter and spring, decrease rainfall in summer. P-ET however, decreases, especially during fall and spring.***
- ***Stronger decrease of P-ET in winter and spring, after removal of less reliable models.***

All nine models:



Removal of less reliable models



Conclusions:

The 9 CMIP5 climate models we evaluated

- ***Share common wet and cold biases, due to underestimate mid-tropospheric ridge in summer, the upper-level wind and westerly low-level winds in spring. Most of the models cannot adequately capture the variations of SC US rainfall with ENSO and the increase of global SST.***

- ***Models consistently project an disproportionally large increase of extreme warm Tmax (86-117F) and Tmin (>80F), and decrease of P-ET in all seasons, except for summer.***

- ***Less reliable models tend to be outliners in climate projections for SC US region. Removal of the less reliable models lead to weaker increase of extreme warm Tmax and Tmin, but stronger projected decrease of P-ET in winter and spring.***

- ***Communicate capability and uncertainty of the climate projections is an useful first step for supporting water resource planning.***

Leading REOF of global SST variance during 1900-2005:

- ***Observation shows the global increase of sea surface temperature (SST) as the leading mode for SST variance (Schubert et al. 2008).***
- ***Few models realistically capture this global increase of SST mode (CCSM4 and MPI)***

Method follow Schubert et al. 2008)

☹: Fail to capture the warming mode as the leading REOF mode